

The Integration of ROADMs into Next Generation Metro Optical Network

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ABSTRACT

Reconfigurable Optical Add/Drop Multiplexers (ROADMs) are going to change the landscape for future metro optical networks. In this paper, we present the detailed design layouts for next generation metro optical network equipped with the most advanced 3rd generation ROADM modules. Mathematical equations have been developed to design complex network architecture based on traffic demand and the characteristics of network equipments. Our proposed design layout for next generation network alleviates some conventional design concepts that will ultimately reduce the capital-and operational-expenditure for the overall network.

Keywords: Next generation network, ROADM, Reconfigurable All-Optical Network, add/drop multiplexer, PLC.

1. INTRODUCTION

As the transmission speeds and network demands are increasing, service providers and equipment vendors are trying to develop new technologies that will help them to build a network with enormous capacity and offer the services to the customers at lower costs. Optical technologies based on modern artifacts help the service providers to maximize their network capacity with reduced cost of bandwidth. This in turn leads to the growth of new sets of applications that set thriving thrust for more bandwidth. This positive feedback cycle for the demand on bandwidth pushes the service providers to the development of Reconfigurable All-Optical Networks (R-AONs). R-AONs combined with Dense Wavelength Division Multiplexing (DWDM) technology can help the service providers to meet the challenge of this surge of traffic demands and also to maximize the utilization of their existing network. R-AONs provide flexibility to the service providers, especially on the dynamic provisioning of their wavelengths that ultimately reduce the Capital-(CAPEX) and Operational-Expenditure (OPEX) of the overall network.

In order to achieve these reconfigurability and transparency over the AONs, service providers have been trying to integrate the service of Reconfigurable Optical Add/Drop Multiplexers (ROADMs) into their present network in combination with DWDM technology. ROADMs can be defined as optical modules capable of adding/dropping or passing through (express) any or all wavelengths present in the DWDM signal with remote management capability. ROADM offers flexibility on the provisioning of wavelengths regardless of how the network changes. It effectively alleviates the need for service provisioning when new services are added to the network and offers flexibility to the service providers on the handling of churns.

In this paper, we present the evolution of ROADM technologies with their integration into the next generation networks. ROADMs with different architectures, developed so far, are integrated into the network based on their functionalities. Further, we concentrate only on the application of Planar Lightwave Circuit (PLC)-based ROADM architectures that recently attract a lot of interest because of their low cost and the simplest manufacturing approach. Detailed procedures with necessary mathematical equations on designing a metro ring network with PLC-based ROADMs are presented in this paper. Using our proposed network model, service providers would be able to design their own network based on

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their traffic demands and other network parameters. Our proposed design layout for next generation network alleviates some conventional design concepts that will ultimately reduce the CAPEX and OPEX for the overall network.

The rest of this paper is organized as follows. Section 2 describes the evolution of ROADM technologies. Section 3 presents the next generation network integrated with different kinds of ROADMs, while Section 4 describes the detailed procedures for designing a future metro ring network with PLC-ROADMs. Finally, Section 5 concludes the paper.

2. EVOLUTION OF ROADMs

In order to add more flexibility to the network, network developers were paying attention on the development and improvement of ROADM architectures for quite a significant amount of time (Figure 1). Initially researchers¹ demonstrated the 1st generation of reconfigurable OADM with Optical Cross Connects (OXC) and Optical-Electrical-Optical (O-E-O) regenerators and showed their integration for future optical networks. Later ROADMs came up with optical circulators², while some researchers³⁻⁵ presented DeMux/Switch/Mux (DSM)-based architectures for ROADM modules. However, these 1st generation ROADM architectures were suffering mainly from large CAPEX/OPEX and high insertion losses because of the lacking of integration among different internal modules.

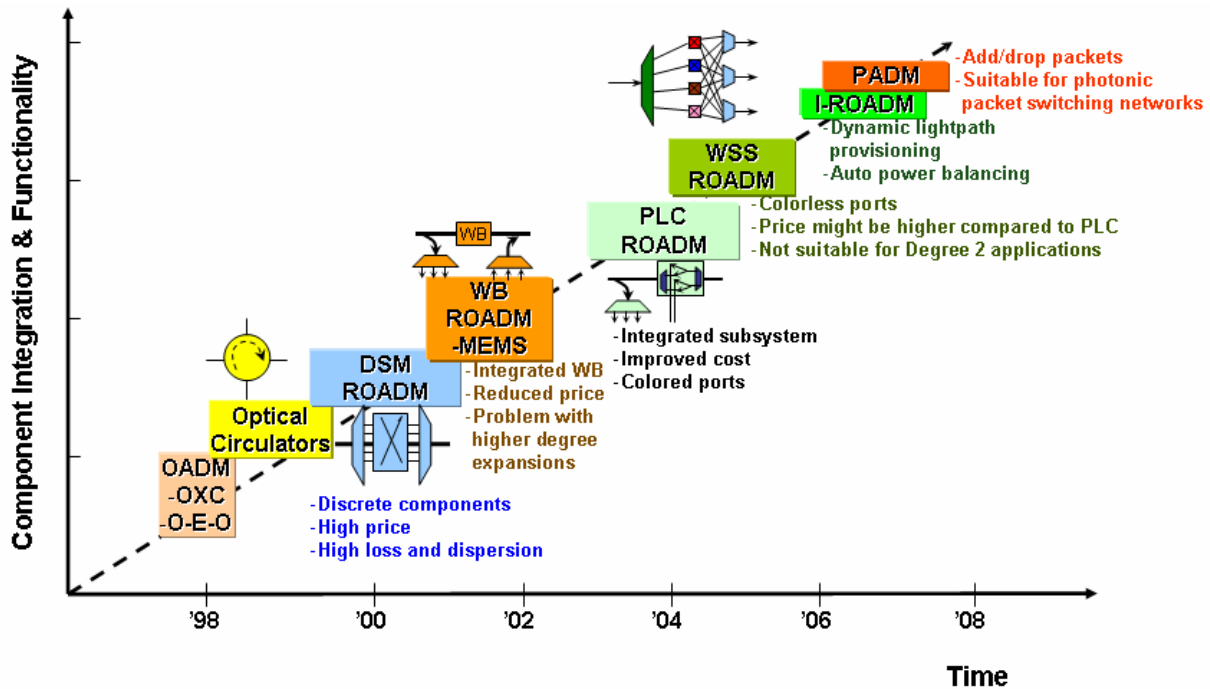


Figure 1: Evolution of ROADM architectures

In order to cut down mainly this huge initial costs, network developers developed integrated ROADM subsystems. Instead of using separate Mux/DeMux and switch modules, compact Wavelength Blocker (WB)-based architectures⁶⁻¹⁰ have been developed that brought the ROADM subsystems to their 2nd generation. These WB-based ROADMs (also known as Broadcast & Select ROADMs) provided more flexibility to the service providers, especially on the dropping of selective wavelengths and then broadcasting new channels¹¹. However, these 2nd generation ROADM modules suffered from two problems: (1) the insertion losses still remained high although the cost was significantly reduced; (2) the design is totally unsuitable for interconnection with other ROADM modules (i.e. for higher degree expansion) as each interconnection requires the installation of additional WB modules that ultimately increases the CAPEX and OPEX for the overall network.

Hence to overcome these problems, some of the researchers¹¹⁻¹² and commercial vendors¹³⁻¹⁴ have recently presented simplified ROADM designs without wavelength blockers using Planar Lightwave Circuit (PLC) technology. These

simplified ROADMs offers flexibility on higher degree expansion bringing the ROADM into its 3rd generation. However, in PLC-based designs each port remains channel specific. Hence, in order to add the flexibility of colorless ports to the ROADM subsystems, network developers^{11,15-18} have introduced Wavelength Selective Switch (WSS)-based architecture that ultimately reduces the total number of ports in the network although it costs more than the PLC-based structure. These highly advanced colorless structures can be constructed using a combination of both PLC and Micro-Electro-Mechanical Systems (MEMS) technology.

Figure 1 shows the evolution of ROADM architectures in terms of integration and functionality over the last half of the decade. Researchers are now paying attention to develop Intelligent ROADM (I-ROADM) subsystems¹⁹ that would be able to reconfigure lightpaths dynamically, and Packet Add/Drop Multiplexers (PADMs) to add/drop photonic packets selectively for the next generation photonic packet switching networks.

3. NEXT GENERATION NETWORKS WITH ROADMs

The installation of ROADMs will change the landscape for next generation metro optical networks. ROADMs with different designs and manufactured with different technologies are soon going to be deployed into the metro core network – a glimpse of which is presented in Figure 2. Note that, due to the integrated functionalities of the ROADM subsystem, there is no need for additional multiplexers/demultiplexers, or Photonic Cross-Connects (PXC) within the node structure. Single Mode Fibre (SMF) spans equipped with Erbium Doped Fibre Amplifiers (EDFAs), or Semiconductor Optical Amplifiers (SOAs) can be laid to connect the ROADM nodes in the ring network. However, for the rest of the paper, we concentrate only on the integration of EDFAs into the network.

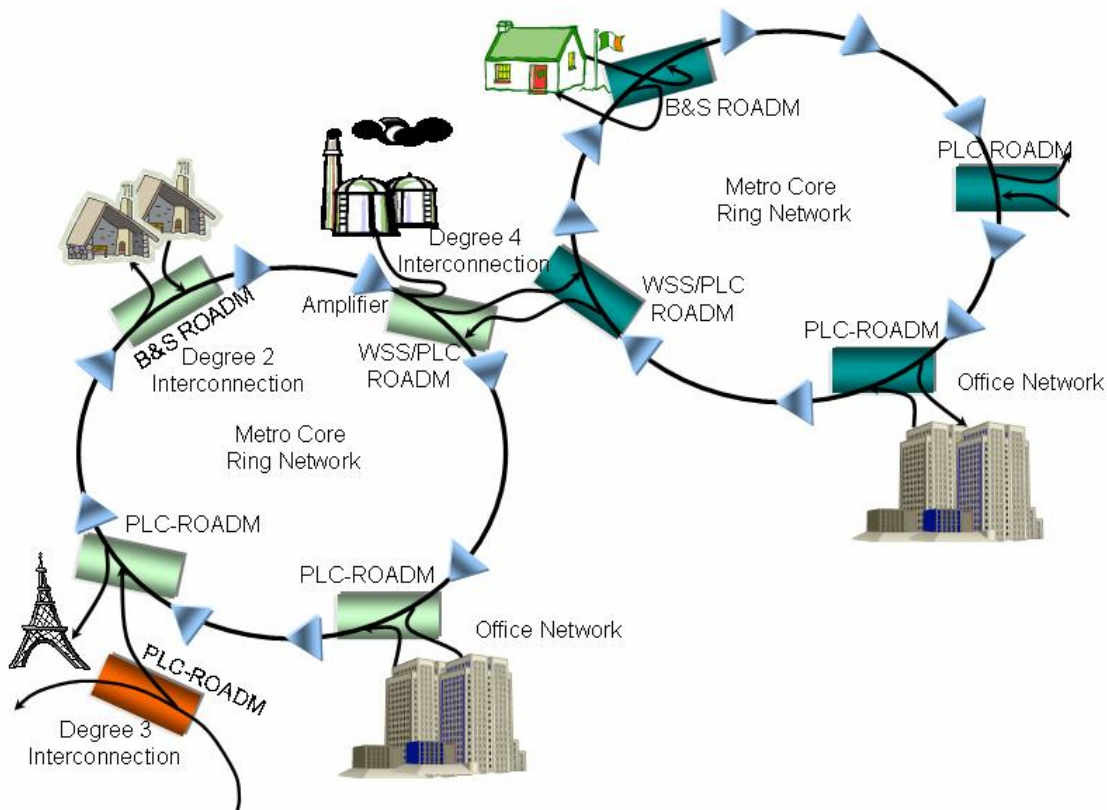


Figure 2: Next generation networks with ROADMs

By using ROADMs, carriers would be able to achieve reconfigurability on wavelengths in every corner of their optical network – starting from the metro core to the small office network. They would be able to control any set of wavelengths to be added/dropped, or forwarded to any part of their network. Based on the functionalities of different

ROADM architectures, the latest Dynamic Channel Equalizer (DCE)-based Broadcast and Select (B&S) architecture²⁰ would be suitable only for Degree 2 applications (i.e. for add/drop and expressing wavelengths), while both PLC¹³⁻¹⁴ and WSS-based ROADMs¹⁵⁻¹⁸ can be used for higher degree of interconnections²¹ as depicted in Figure 2. However, due to the high cost of the present WSS-based colorless ROADMs¹⁷⁻¹⁸, they may not be a cost-effective solution only for Degree 2 applications. One of the best features occurs with ROADMs is the reconfigurable transparent ring-to-ring interconnections²² (Degree 4 application) that will alleviate the use of costly Optical-Electrical-Optical (O-E-O) regenerators and Optical Cross Connects (OXC) from the network interconnections. ROADM can also be used in schemes such as gain equalization and dispersion compensation techniques. Almost all the ROADM devices appear with east-west separability that provide 1+1 protection and bi-directional traffic flow, thus supporting the present Synchronous Optical Networks (SONET)/Synchronous Digital Hierarchy (SDH) networks. Service providers should look for their own requirements e.g. maximum planned capacity, channel bandwidth requirements, wavelength granularity and the type of their network before going to deploy ROADMs into their network.

4. DESIGNING A METRO AREA NETWORK

Many researchers^{1,3,9,23} have already shown the integration of ROADMs into next generation optical network. However, all of their design layouts have been presented only from the network layer point of view without revealing any details about network design parameters such as the associated fibre span, and the placement of optical amplifiers in the network. In this section, we present detailed design layout for the next generation metro optical network equipped with ROADMs as depicted in Figure 3. For simplicity, we present only a unidirectional ring network where each node consists of a single PLC-based ROADM module. Service providers can use the passive drop module as the receiving demultiplexer while transmitting new channels using the reconfigurable add ports. A common control interface can be developed to control the ROADMs and the gain of the associated EDFAs in order to achieve flexible control and reconfigurability over the core network. Since the optical power of the newly added channels are usually stronger than that of the express-channels, internal VOAs of the ROADM module have to be used to balance the power levels so that all the channels coming out of the node have the same level of optical power¹⁹.

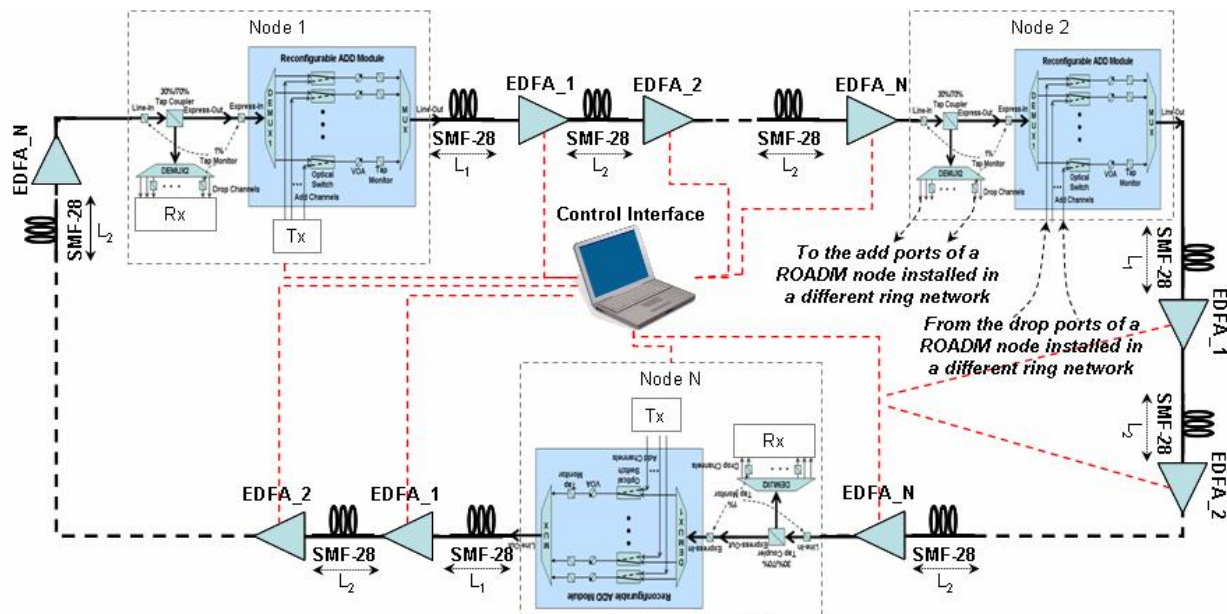


Figure 3: A layout example for next generation metro optical network

It is important to note that the EDFAs installed in the system, work within a particular input power range. The length of the fibre segments mainly depends on the input power range and the gain of these EDFAs. Considering the channels coming out of the node have attained the same power level, the combined channel power must have to be within the input power range of the EDFA. Otherwise, the combined channel power may become too strong to drive the

corresponding EDFA into saturation and in such case, the EDFA will not work and the system will behave like a single line failure. Hence, the combined input power at the EDFA can be expressed as:

$$P_{EDFA_{IN}} = P_{N_{dBm}} = 10\text{Log}_{10} \left(N * P_{Ch_{mw}} \right); P_{EDFA_{MAX}} \geq P_{N_{dBm}} \geq P_{EDFA_{MIN}} \quad (1)$$

where $P_{EDFA_{IN}}$ defines power at the input of EDFA, N is the total number of channels and $P_{N_{dBm}}$ is the combined power all the channels coming out of the node. $P_{Ch_{mw}}$ defines the power of each channel in mW, while $P_{EDFA_{MAX}}$ and $P_{EDFA_{MIN}}$ denote the maximum and the minimum power range within which the EDFA can work properly. From (1), the required power level for each channel can be obtained as:

$$\begin{aligned} P_{EDFA_{IN}} &= 10\text{Log}_{10} \left(N * P_{Ch_{mw}} \right) \\ \Rightarrow N * P_{Ch_{mw}} &= 10^{\left(\frac{P_{EDFA_{IN}}}{10} \right)} \\ \Rightarrow P_{Ch_{mw}} &= \frac{1}{N} 10^{\left(\frac{P_{EDFA_{IN}}}{10} \right)} \\ \Rightarrow P_{Ch_{dBm}} &= P_{EDFA_{IN|dBm}} - 10\text{Log}_{10} N \end{aligned} \quad (2)$$

where $P_{Ch_{dBm}}$ defines the power of each channel in dBm. If the EDFA works within the power range defined by $P_{EDFA_{MAX}} \geq P_{EDFA} \geq P_{EDFA_{MIN}}$, the power level of each channel must have to be within the range $P_{Ch_{MIN}} \leq P_{Ch} \leq P_{Ch_{MAX}}$, where

$$P_{Ch_{dBm|MIN}} = P_{EDFA_{dBm|MIN}} - 10\text{Log}_{10} N \quad (3)$$

$$\text{and } P_{Ch_{dBm|MAX}} = P_{EDFA_{dBm|MAX}} - 10\text{Log}_{10} N \quad (4)$$

Considering 0.2 dB/km power loss through the SMF-28 fibre and neglecting dispersion and other non-linear effects, the maximum possible length of the fibre segments will be,

$$L_{1|MAX} = \frac{P_{N_{dBm}} - P_{EDFA_{dBm|MIN}}}{0.2} \quad (5)$$

$$L_{2|MAX} = \frac{\text{Gain}_{EDFA_{dB}}}{0.2} \quad (6)$$

where L_1 is defined as the length of the first fibre segment between a node and an EDFA, while L_2 defines the fibre span between two EDFAs. Both $L_{1|MAX}$ and $L_{2|MAX}$ define the maximum values for L_1 and L_2 respectively. A numerical example is presented below based on the parameters in Table 1.

Table 1: Parameters for the Example

Name of Parameters	Value
Number of Channels, N	4
Power of the channels arriving at the input of <i>Node 1</i>	-13 dBm/channel
Losses through <i>Node 1</i> :	
Express channels	12 dB
Add channels	6 dB
Transmitted power	-3 dBm/channel
Maximum EDFA gain	20 dB
EDFA input power range	-26 dBm to -17 dBm
Losses in fibre	0.2 dB/km

Here, $P_{EDFA_{MIN}} = -26$ dBm and $P_{EDFA_{MAX}} = -17$ dBm. From (3) and (4),

$$P_{Ch_{MIN}} = -26 - 10 \log_{10}(4) \approx -32 \text{ dBm}, \text{ and } P_{Ch_{MAX}} = -17 - 10 \log_{10}(4) \approx -23 \text{ dBm}$$

Hence, the power of each channel at the input of the EDFA must be within the range of -32 dBm to -23 dBm. Since the express-channels acquire a loss around 12 dB through the ROADM node, each express-channel coming out of *Node 1* will maintain a power level of around -25 dBm. However, each newly added channel at the output of *Node 1* will attain a power level of around -9 to -10 dBm (considering transmitted power -3 to -4 dBm plus insertion loss of -6 dB). Internal VOAs are then required to be activated to attenuate the newly transmitted channels by 15 to 16 dB in order to make a balance among the power levels.

Hence, $P_{Ch_{mW}} = 0.003162$ mW; $P_{N_{dbm}} = 10 \log_{10}(4 \times 0.003162) \approx -19$ dBm. From (5) and (6),

$$L_{1|MAX} = \frac{P_{N_{dbm}} - P_{EDFA_{dbm}|MIN}}{0.2} = \frac{-19 - (-26)}{0.2} = 35 \text{ km}; \quad L_{2|MAX} = \frac{Gain_{EDFA_{db}}}{0.2} = \frac{20}{0.2} = 100 \text{ km}$$

Therefore, the maximum possible length of the fibre segment between the node and the *EDFA 1* will be around 35 km ($= L_{1|MAX}$), while between *EDFA 1* and *EDFA 2*, it will be around 100 km ($= L_{2|MAX}$). However, in reality due to dispersions, Amplifier Spontaneous Emissions (ASE) and other non-linear effects, both L_1 and L_2 are less than their maximum anticipated value. In a 2.5 Gbps transmission system with 4 channels, the effective value for L_1 is usually around 30 km²², and for L_2 , it is around 60 km maintaining the latest FEC requirement⁸. Note that, two important facts are revealed out of this design example. First of all, the optical signals coming out of the PLC-ROADM module are strong enough to place a significant amount of fibre span before placing the first EDFA beyond the ROADM module that will ultimately reduce the CAPEX and OPEX for the overall network. Secondly, the proposed ROADM integration for next generation network is suitable only for high channel count applications. The more number of channels presents in the system, the longer the distance the channels will be able to travel beyond the ROADM node before facing the first EDFA. However, the mathematical equations, presented in this paper for obtaining the maximum possible fibre span, do not consider factors such as channel spacing, crosstalk, dispersions and other non-linear effects for which the effective fibre length will be always less than their maximum anticipated value.

5. CONCLUSIONS

Researchers and manufacturing vendors have been trying to improve the integration and functionality of ROADMs over the last half of the decade. Next generation networks equipped with ROADMs of different designs and functionalities are presented in this paper. Detailed schemes for designing a next generation metro ring network with ROADMs are illustrated where each node contains only a reconfigurable add/drop module without any supporting EDFAs. The proposed design layout alleviates some conventional concepts that will help to reduce the initial installation costs and operational expenditure for the overall network.

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